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# COUNTERS FOR AIRBORNE USE

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## FOREWORD

This report was prepared by the Psychology Branch, Aero Medical Laboratory, Directorate of Research, Wright Air Development Center under Research and Development Order No. 694-38, "Human Engineering Consultation Service," with Mr. Melvin J. Warrick as Project Engineer.

## ABSTRACT

This report presents an integrated survey and interpretation of psychological research relevant to the design of counters for use on airborne equipment. The merits and demerits of a counter as compared with other methods of presenting information in typical applications are discussed. Such design problems as the speed and direction of rotation of a counter and the location and mode of operation of its associated control are analyzed in detail.

## PUBLICATION REVIEW.

This report has been reviewed and is approved.

FOR THE COMMANDER:

JACK BOLLERUD
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Directorate of Research

## INTRODUCTION

Counters of the general type shown in Figure 1 are becoming an increasingly popular method of displaying information to aircrew members. This is probably due to the increased precision required in operating airborne equipment and to the recognized advantages of a counter in presenting multi-digit numbers such as Longitude W $172^{\circ}$ 38'.


Figure 1: Typical Counter

When considering counters for the display of such information as distance, elapsed time, fuel, navigational coordinates, etc., there arise a number of practical questions specific to counters: When should a counter be used? What are its advantages and disadvantages? Which direction should a counter rotate to indicate an increase? How fast can it rotate and still be readable? What type of control should be used to set the counter? Which direction should the control move to cause the counter reading to increase?

In addition to these and similar questions, such problems as numeral size and type, lighting, location, use of color and labeling are common to other methods of presenting information visually (See Baker & Grether, 5). None of these problems relating to counter design are entirely independent. Furthermore, any conclusions that the reader may draw from this report should be tempered by considerations of the use to which the counter will be put, when it will be used, the meaning or significance of its reading, and its relation to the other equipment used by the operator. For example, it might sometimes be desirable to compromise the counter design to conform with the other equipment used by the operator. To illustrate this point Warrick (22) has presented evidence to suggest that it is better to accept a reversed direction-of-motion relationship between a control and its indicator if, by so doing, the motion relationship is made consistent with the other equipment on the operator's panel.

That all counter design problems have not been solved is evidenced by the fact that one need not search far to find gross inconsistencies in those counters now in use on Air Force equipment. Experimental evidence on counter design is conspicuously lacking. Thus the ensuing discussion is largely tentative and perhaps somewhat speculative. However, it is believed that even a premature discussion of counter design problems may be of value, if it does nothing more than promote consistency between, and standardization of, counter designs.

## DESIGN CONSIDERATIONS

### When Should a Counter Be Used?

Probably the most important single problem is to determine when a counter should be used and when it should not - a problem that can be answered only on the basis of the advantages and disadvantages of a counter as compared to other methods of presenting information in the specific applications under consideration. Counters are not universally better or worse than other methods of visually displaying information.

For presenting static, quantitative information, accurate to five significant figures, Grether (9) found a counter to be far superior to eight other types of indicators, including the more conventional designs. For example, he found that it took some seven seconds longer, on the average, to read a conventional three-pointer altimeter than to read comparable information from a counter. Furthermore, practically no errors were made in reading the counter, whereas more than 11% of the readings of the three-pointer altimeter were in error by a thousand feet or more. Chapanis (1) observed that radar operators could set a cursor over a target-pip and then read bearing from a counter much more rapidly and accurately than they could read it directly from the cursor and its associated compass rose. However, he noted that operators experienced some difficulty in manually setting a bearing number directly into a counter, since they had to stop occasionally to read the counter. He does not comment on the accuracy of these settings. It is surmised that the setting of a conventional dial to 3-digit or greater accuracy could be rather difficult if not impossible. Kappauf and Smith (14), for example, report that reading errors increase quite rapidly when more than 200 units are presented on a conventional 2.8 inch diameter, single-pointer indicator. In this connection it might be pointed out that counters are not as subject to parallax errors as are conventional dials. This means that the engineer may have greater latitude in the placement of counters providing, of course, the lighting is adequate and the view unobstructed.

In spite of certain advantages that counters may have, they also have some limitations as compared to other methods of displaying information visually. For example, it is relatively easy to check read a conventional rotating-pointer type instrument by merely noting the position of the pointer. With a counter, however, it is necessary that the operator read and remember at least one, and probably more, digits. Connell (4) found a linear decrease in speed and absolute accuracy of check reading with each additional drum beyond two. With a panel of four instruments mounted side by side, her subjects took 1.4 seconds, on the average, to determine whether or not the same reading appeared on each of four counters and make an appropriate manual response; whereas they took only .9 seconds to determine whether or not the same reading appeared on each of four rotating-pointer type instruments and make the appropriate manual response. As a matter of fact, it took Connell's subjects almost as long to check a panel of four counters as it did Warrick and Grether's (19) subjects to check read a panel of 16 rotating-pointer type instruments. Furthermore, Connell found that her subjects made almost twice as many errors in checking the counters as they did in checking the pointer-type presentations. Thus it appears that counters are not as satisfactory as conventional single-pointer dials if it is desired that the operator be able to check read the information rapidly.

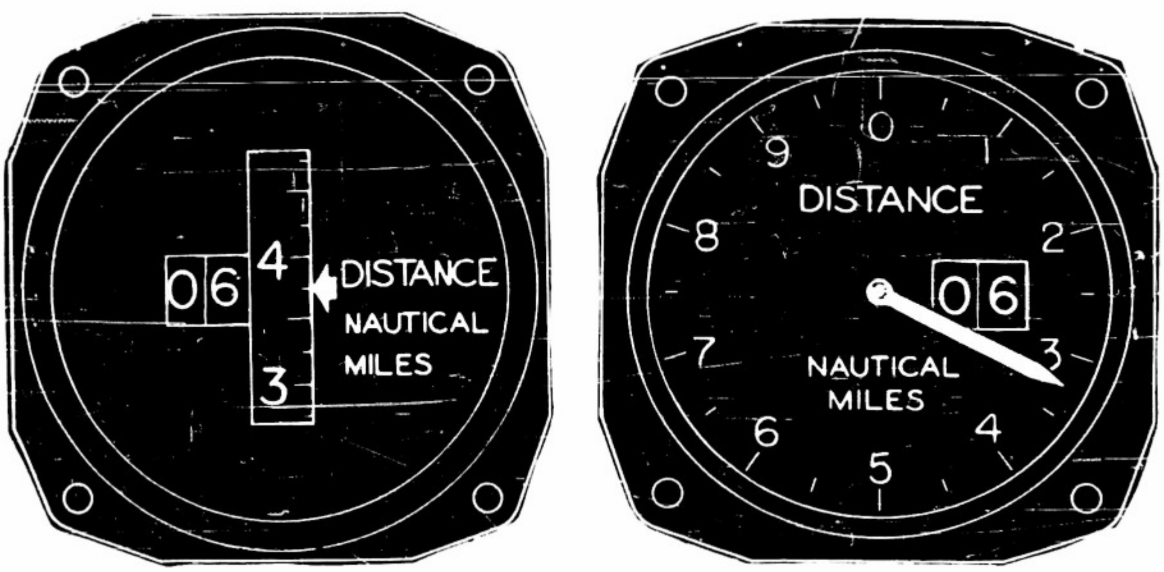
In the experiments cited above the operator's task was to compare the readings presented on a number of instruments simultaneously. When the operators were required, as is often the case, to accurately check read a single instrument from his memory of its previous reading, Connell found a counter to be as satisfactory as a rotating-pointer instrument. This suggests that if, to be check read, the instruments must be read very precisely but not necessarily rapidly, counters may well be considered. It should be remembered, however, that in Connell's experiments there was little reason for the subjects to forget or become confused, hence the findings may not be entirely applicable to the more usual aerial situation.

Counters also have definite disadvantages, as compared to the rotating-pointer type display, if it is desired to present directional or rate information or operating ranges or limits. Consider the problem of maintaining an airplane at a heading of $30^{\circ} \pm 2^{\circ}$. A pointer could rather obviously indicate a northeasterly direction even if there were no numbers on the scale surrounding it. Should the pilot deviate from the desired heading, both the direction and rate of his deviation would be indicated. Furthermore should the air be rough, causing the heading to oscillate, the pilot could readily observe the amplitude of these fluctuations from a pointer and make a reasonable guess as to the average heading. Although experimental evidence is lacking, it would appear likely that an operator might experience considerable difficulty in using a counter-type display for such purposes as described above. On the other hand, if the directional or rate information rather naturally falls into a dichotomy which is not likely to change sign rapidly, such as Latitude: North or South, Variation: East or West, or exceeding, or not, a critical speed, an additional drum presenting this information could be added to the counter.

It is occasionally proposed that an operator will desire, or be required, to interpolate between digits on the highest speed counter drum. In this case the problems are similar to those encountered in using an indicator consisting of a scale moving behind an open window. Sleight (15), using very brief (0.12 second) tachistoscopic exposures, has shown that quantitative information can be obtained more accurately from a moving-scale type indicator than from a rotating-pointer type indicator. For very brief exposures, Christensen's (3) findings support those of Sleight. For exposures of .5 seconds or longer, however, Christensen found the rotating-pointer type indicator to be superior to the rotating-dial type indicator. In any event, the results may not be particularly applicable since neither the dial nor pointer was moving at the time of exposure and since, in the laboratory situation, the subject could be fixated near the proper position before the dial was exposed.

Fitts (8) has pointed out that the moving-scale type of indicator, when in motion, is inherently ambiguous. If the scale moves right or up to indicate an increase, the numbers must increase from right to left or top to bottom, making interpolation between them somewhat confusing. For example, Christensen (2) studying aircraft plotters found an appreciable increase in the number of errors in reading a degrees scale increasing to the left as compared to the same scale increasing to the right. On the other hand if the numbers increase in the appropriate direction, that is left to right or bottom to top, the scale must move to the left or down to indicate an increase. Therefore, to avoid ambiguity as to the direction in which the scale increases, it is imperative that at least two clearly legible numbers be visible at all times. In the case of conventional counters, one, or at best only a part of two numbers appear in the opening. This, of course, makes interpolation between numbers difficult if not impossible. Fortunately there is no real necessity for requiring the operator to interpolate between numbers. The same function can be achieved by adding an additional drum to the counter to extend the accuracy to the next significant digit. On the other hand, the resulting increase in precision may result in some confusion when only gross readings are required. To insure that the counter's digits are always readable and to prevent the confusion which might arise in interpolating between digits, it is suggested that the counter drums snap, rather than move smoothly, from one digit to the next.

Unfortunately, it is not always feasible to provide an additional snap-action drum. One compromise appears to be offered by increasing the size of the units drum and providing an enlarged window so that at least two digits are always visible. (See Figure 2 a). Another possibility suggested by Grether's research (9) is to combine a counter and moving pointer. For example, the first two digits of a three-digit number could be presented on a counter and the last digit on a moving pointer. (See Figure 2 b). This arrangement preserves some of the advantages of both types of indicators, provides a convenient means of interpolating, gives directions and rate information, and for small deviations can be check read easily.




(a) (b)

Figure 2: Compromise Counter Designs Allowing Interpolation

To summarize, it appears that counters have certain advantages when it is desired to present precise quantitative information, if only gross directional or rate-of-change information is required. If, in addition to precise quantitative reading, the instrument is to be check read, if rate or directional information is to be obtained from its movement, or if the operator must interpolate or average between readings, a counter may be inferior to other methods of presentation.

How Fast Should the Counter Rotate?

In a sense this is an unanswerable question. If one counter drum turns so rapidly that the operator cannot read it, he simply reads the next slower drum. However, there is no point to having a high-speed drum and expect people to act on its reading if the speed of rotation is so high as to make reading difficult if not impossible. Experience with motion pictures would suggest that with speeds of 16 digits per second or higher, the digits are very likely to lose their identity completely and at higher speeds the direction of rotation of the drum may be obscured, particularly if the numbers snap into place. Although experimental evidence is lacking, more appropriate speed appears to be about one digit per .5 second which is about the time required to initiate and complete a simple control response to a visual signal. (Hick, 10)

For automatically setting the counter, this speed is probably much too slow. It is therefore suggested that a multiple-speed reset device be used by which the operator can approximate the desired setting at high speed and make precise setting at a slower speed. Stump (16) has presented evidence that a conventional spring-loaded toggle switch can be moved to the on position and back to the off position in .1 second or less. This suggests that even with reset rotation rates as high as 10 digits per second the operator could easily set the counter to any desired precise value. If it is desired that the counter be reset to zero only, the above discussion is not particularly pertinent. For this purpose the simpler, conventional, manual or automatic high-speed reset appears quite adequate.

Allied with the problems of rotation speed is that of the gear ratio between the control and counter when a manual setting device is used. If the manual device is a thumb operated knob colinear with the counter, the counter drum should move in the same direction and at the same rate as the control. If a rotary knob is used, the gear ratio depends on the circumstances under which it will be set. If the counter will never be set except when the equipment is on the ground, the operator can probably tolerate a very high ratio, perhaps 10 revolutions (100 digits) of the highest speed counter drum per one revolution of the knob. If, however, the counter must be set to the nearest digit under turbulent conditions, a much lower ratio is suggested. Experimental evidence lacking, it is suggested that one digit represent an easily discernable and remembered amount of control rotation, say 45° per digit or 8 digits per revolution of the control. This would perhaps be most satisfactory if the operator is required to adjust the counter by only one or two digits. If it is desired that the counter be reset by five, ten, or more digits a ratio of 10 digits per revolution of the control is perhaps more appropriate. With this ratio the task of adjusting the counter by more than a few digits would be time consuming. For this reason it is suggested that an additional high-speed shift or automatic device be provided to permit rapid coarse settings, or to speed ground setting operations. In some applications an operator may wish to correct the reading of an active counter by adding or subtracting an increment rather than resetting it to a new number. In such cases it is suggested that the reset control knob be provided with a pointer mark moving against an unlabeled scale divided into unit divisions.

### Vertically Oriented Counters.

Occasionally, counters are mounted vertically, the numbers being read from top to bottom. There appears to be no experimental evidence bearing directly on this arrangement nor on the merits of this arrangement as compared with the conventional horizontal arrangement. There would seem to be no special advantages to the vertical arrangement, and it might be somewhat harder to read. Experimental evidence lacking, it is assumed that, where relevant, the comments of the preceding sections apply equally well to vertical counters.

### In Which Direction Should a Counter and Its Control Rotate?

The problem of the direction of scale increase and of the corresponding direction of control motion is so complicated that no general answer can be offered at this time. It is hypothesized, by some (e.g., Baker and Grether, 5), that there will be fewer reading and setting errors if the scale numbers progress from left to right or bottom to top. Furthermore, it is argued, this is more consistent with pointer type indicators if one visualizes the pointer as being fixed and the scale moving.

On the other hand, it is conventional that control motion up, clockwise or to the right produces an increase; and it is fairly well established (e.g., Vince and Mitchell, 18; Warrick, 20) that the control should move in the same direction as the corresponding indicator or function. This then requires, at least for the conventional location and orientation of the controls, that the scale numbers progress right to left or top to bottom. At the moment, no theoretically defensible solution to the two conflicting requirements is apparent; although Bradley's research (6) suggests that with clear, sharp, properly spaced numbers and properly designed scales the likelihood of reading or setting errors with right-to-left scales may be negligible.

A practical, but extremely tentative compromise solution which may minimize some of the difficulties is possible, but lacking empirical validation it cannot be recommended without qualification. Assuming that the numbers must progress from left to right or bottom to top and that motion of the control up, clockwise, or right must result in an increase, the problem becomes one of locating or orienting the control so that there is minimum conflict between its direction of motion and that of the counter. Thus for horizontal counters a rotary control could be located to the left, or at least lower left, or a switch could move to the right for an increase. In the case of vertical counters, the rotary control could be located above the counter or at least above its lower dial, or a switch could move up for an increase.

In certain situations, there may be common conventions which override all other considerations and thus dictate the movement relationship. For example, East is pictured as "to the right" and increasing longitude "to the left" in the Western hemisphere. Or, in a different vein, if the control, e.g., a knurled knob, appears to be part of the counter drum, it is obvious that the counter and control should move in the same direction. In these situations, the preceding discussion concerning the direction of scale or control increase and motion relationship correspondence may be void.

## SUMMARY

An attempt has been made to survey, integrate and interpret psychological research relevant to the design of counter-type displays. It is apparent that

many crucial experiments still remain to be done. For this reason the suggestions offered below should be applied with considerable caution and reservation, recognizing that they may very well be invalidated by future research and new information and techniques.

1. It is suggested that counters may be used most advantageously for the presentation of precise quantitative information requiring no interpolation between numbers.

2. It is not recommended that counters be used to present information from which the operator is to derive directional or rate information or to present information which will be used for check-reading purposes.

3. In reference to the design of counters:

a. It is suggested that the numbers snap into place, normally following each other at a rate no faster than about two per second.

b. If a toggle switch is used as a setting control, it is suggested that the counter speed be no greater than 10 digits per second.

c. If a manually operated, rotary knob setting control is used, it is recommended that a ratio of $36^{\circ}$ or $45^{\circ}$ control knob rotation for one-digit counter movement be used.

d. The direction in which a counter should rotate to indicate an increase has not yet been established. It has been suggested that movement downward or to the left is most consistent with conventional moving-pointer indicators. Regardless of which direction the counter rotates to indicate an increase, it is clear that the counter and its control should move in the same direction, or at least not in opposite directions. Furthermore, it is conventional that control movements clockwise, up or to the right result in an increase. Thus:

(1) If downward movement of a horizontal counter results in an increase, a clockwise-for-increase control should be located to the left of the counter. If a toggle switch control is used, it should be located so that moving it to the right results in an increase.

(2) If leftward movement of a vertical counter results in an increase, a clockwise-for-increase control should be located above the counter. If a toggle switch is used, it should be located so that moving it up results in an increase.

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